Measuring the linear polarization of γs in 20 - 170 GeV range

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The Na59 collaboration aims to measure the linear polarization of its photon beam in the 20-170 GeV range, using an aligned thin crystal. The tracks of e^-/e^+ pairs created in two different crystal targets, germanium and diamond, are reconstructed to obtain the photon spectrum. Using the polarization dependence of the pair production cross section in an aligned crystal, photon polarization is obtained to be 55% at the vicinity of 70 GeV.

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I. INTRODUCTION

The pair conversion in a thin crystal was proposed in the 1960s as a polarization measurement method for γs in the few-GeV range [1]. The fact that both the pair production cross section and the sensitivity to γ polarization increase with increasing γ energy makes this method superior to others, such as the pair production and photonuclear methods, for present and future γ beamlines. The Na59 collaboration utilized it to map the polarization of its γ beam.

A convenient way of creating a γ beam with a predictable linear polarization spectrum is using the Coherent Bremsstrahlung (CB) [3] radiation from unpolarized electrons. If the electron beam interacts coherently with the atoms in different planes in the crystal, thus satisfying the Laue condition, bremsstrahlung photons emerge with peaked energy values corresponding to selected vectors of the reciprocal lattice. The energy and intensity of these peaks are tunable by carefully aligning the lattice planes with respect to the beam. In CB, the maximum of the polarization degree coincides with the maximum of the intensity peak and polarizations up to 70% have already been observed [4] for 6 GeV electrons, and up to 60% for higher energies [5].

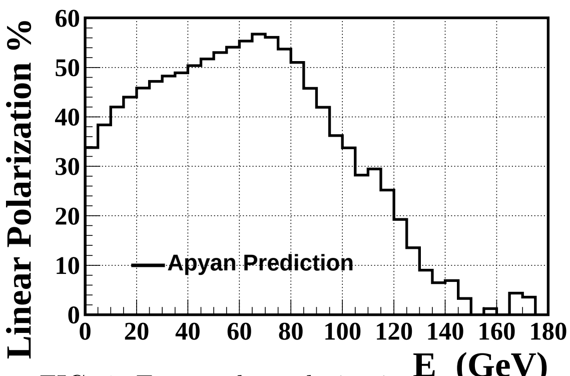

FIG. 1: Expected γ polarization

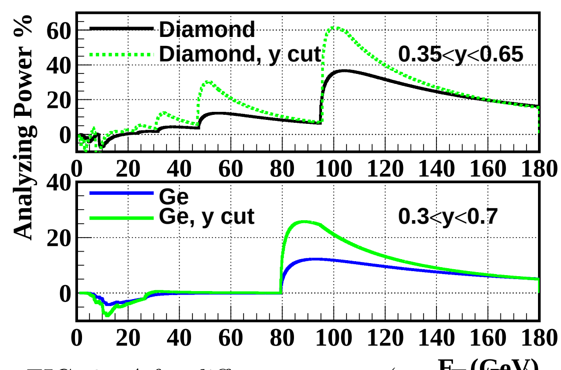

FIG. 2: A for different targets ($y \equiv E_e/E_\gamma$)

The Na59 collaboration used 1.5cm thick Si single crystal with the electron beam making an angle of 5$m$rad from the <001> crystallographic axis and about 70μrad from the (110) plane. This choice yields a γ beam with a maximum polarization of about 55% in the vicinity of 70 GeV, as can be seen from Figure 1. This Monte Carlo calculation took into account the divergence (48μrad horizontally and 33μrad vertically) of the electron beam as well as its energy uncertainty of 1%. The notation used is Stoke's polarization decomposition with Landau convention:

$$P_{\text{linear}} = \sqrt{\eta_1^2 + \eta_3^2} \qquad P_{\text{circular}} = \sqrt{\eta_2^2} \qquad P_{\text{total}} = \sqrt{P_{\text{linear}}^2 + P_{\text{circular}}^2} \quad . \tag{1}$$

With the Na59 angular settings, the photon polarization was solely created in the η_3 direction. We therefore made two distinct measurements, one of η_3 to find the expected polarization, and

another of η_1 to show that it was consistent with zero. The method for these two measurements is based on the birefringence properties of the crystals. Since the imaginary part of the refraction index is proportional to the pair production probability, we defined $\sigma_\parallel$ ($\sigma_\perp$) as the pair production cross section when the selected crystallographic plane on the analyzer was parallel (perpendicular) to the photon polarization. The experimentally relevant quantity is the asymmetry between these two cross sections and it gives the γ polarization, $\mathcal{P}$, through

$$a \equiv \frac{\sigma_\parallel - \sigma_\perp}{\sigma_\parallel + \sigma_\perp} = A \times \mathcal{P} \quad , \tag{2}$$

where A is the so called "analyzing power" of the crystal, and it represents the asymmetry for a 100% polarized beam. A way of increasing the analyzing power which can be computed accurately by MC techniques, is to select the "quasisymmetrical" pairs [7] in which the e^- and e^+ share the γ energy almost equally. Figure 2 shows the analyzing power with and without this selection (y cut) for two different analyzer crystal choices. This cut also reduces the relative statistical error on the asymmetry measured through the number of pair events in parallel ($N_\parallel$) and perpendicular ($N_\perp$) configurations :

$$\frac{\delta a}{a} = \sqrt{\frac{1-a^2}{a^2(N_\parallel + N_\perp)}} \quad . \tag{3}$$

II. EXPERIMENTAL SETUP AND ANALYSIS

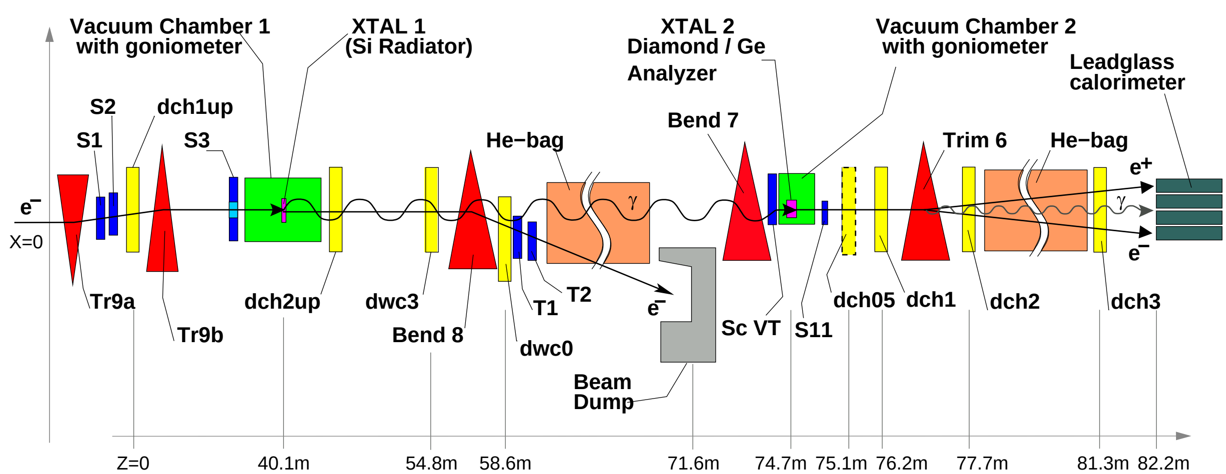

FIG. 3: Experimental setup

The schematic view of the Na59 experimental setup is given in Figure 3. A tertiary 180 GeV electron beam from CERN SPS was sent onto the radiator crystal aligned with a goniometer of 2 μrad precision. Three upstream tracking chambers defined the entrance and exit angles of the electron beam. The scattered electron beam is deflected toward the beam dump with a dipole

magnet, and passed through a tracking chamber to measure its remaining energy. The γ beam is assumed to follow the direction of the incoming electrons impinged on the crystal target called the analyzer.

The momenta of the pairs produced in the analyzer crystal are measured with a magnetic spectrometer consisting of a dipole magnet, two drift chambers (dch) downstream and one drift chamber upstream of it for the Ge target. For the case of the multi-tile synthetic diamond target [8], a second dch (dch05) was added right after it to improve the tracking. The dch tracked charged particles with a resolution of $100\mu m$. The total radiated energy was recorded with a 12 segment leadglass calorimeter with a resolution of $\frac{\sigma}{E} = 11.5\%/\sqrt{E}$.

In the offline analysis, after applying beam quality cuts, the e^- beam trajectory was found and the impact point on both radiator and analyzer crystals were determined for fiducial volume requirements. To reconstruct the photon energy in the pair spectrometer, an optimizing algorithm compensating for chamber inefficiencies and limited geometrical acceptances was employed [9]. The vertex reconstruction on the diamond analyzer allowed veto of the inter-tile events as well as the ones coming from a misaligned tile [8].

III. RESULTS AND CONCLUSIONS

To measure a polarization component, the asymmetry in Equation 2 was experimentally constructed by taking data at two perpendicular analyzer crystal angular orientations. After the mapping of both crystals was done, the data recording time for each pair of angles was two hours at the Na59 e^- rate of 20KHz. To minimize the systematics, two measurements were performed with the analyzer 180 degrees apart. The measurement shown in Figure 4 ensures that there is no "false" asymmetry introduced due to analyzer crystal angular setting. The zero asymmetry in Figure 5 shows that all linear polarization was in η_3 direction as expected. Figures 6 and 7 show the measured asymmetries with and without the y cut for different analyzer crystals. The asymmetries are in good agreement with theoretical predictions in both cases. In all Figures, the shaded region is the statistical error band for the increase in asymmetry (Δasy) due to quasisymmetrical pair selection and it confirms the non statistical nature of the effect. Comparing Figures 6 and 7, we conclude that multi-tile synthetic diamond is a better choice than Ge as an analyzer, since for the same γ polarization it yields a bigger asymmetry thus an easier measurement.

These results show that Na59 setup measures the polarization of high energy photons with good accuracy. This measurement capability was used in other studies [10] in Na59 research program,

and will be reported elsewhere. We believe the presently investigated crystal polarimetry technique is also applicable in future high energy photon beamlines as a fast monitoring tool.

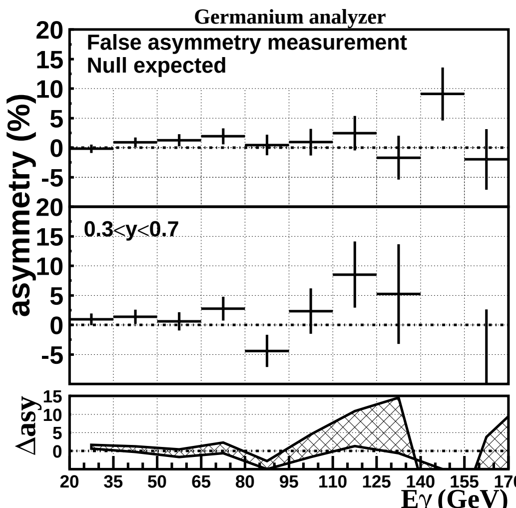

FIG. 4: False asymmetry in Ge

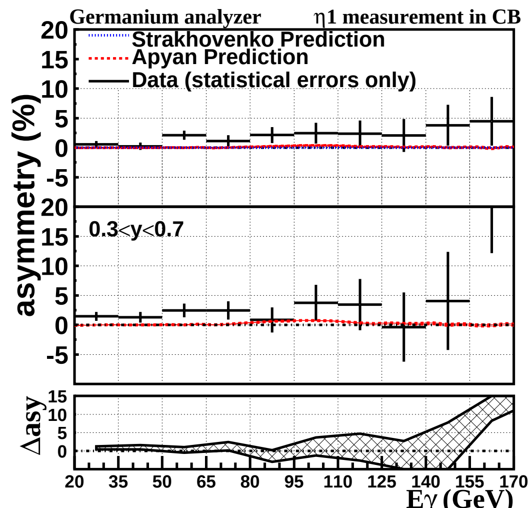

FIG. 5: η_1 measurement with Ge target

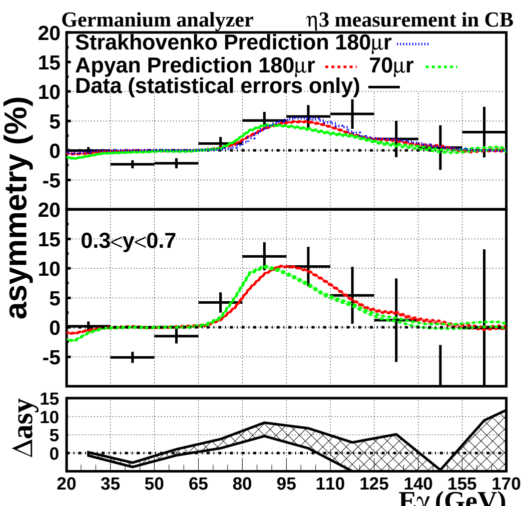

FIG. 6: η_3 measurement with Ge target

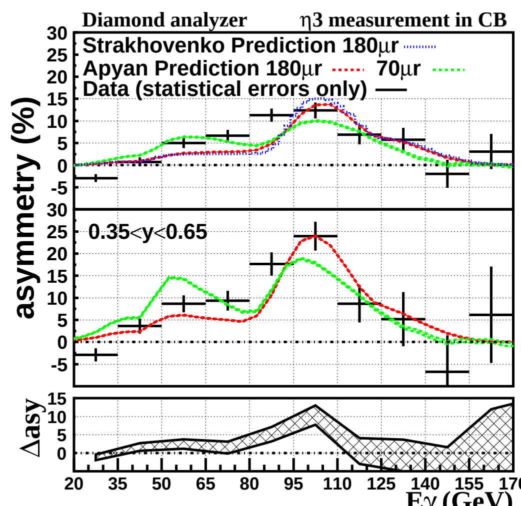

FIG. 7: η_3 measurement with diamond

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